

Orphans in 'Botanical' Diversity

David L. Hawksworth

International Mycological Institute, Bakeham Lane, Egham, Surrey TW20 9TY, United Kingdom.

Abstract

The range of organisms included in 'botany' has included ones now placed in five different kingdoms of Life (*Bacteria*, *Chromista*, *Fungi*, *Plantae* and *Protozoa*). The hypothesis that 'botanical' organisms other than in the kingdom *Plantae* should be viewed as 'orphans' within botany is tested in relation to different attributes of human orphans: these lack close relatives, are misunderstood, excluded from 'family' events, unnamed, ignored or overlooked, have few carers, and are inadequately provided for. No data contrary to the hypothesis was discovered. 'Botanical' orphans are to be valued for their crucial ecological roles, potential as bioindicators, and as a source of exploitable attributes. The 'botanical' orphans merit human attention from both altruistic and selfish motives, and resourcing commensurate with their importance.

Introduction

In this contribution I endeavour to highlight the issue that some groups of organisms, many of importance to humankind and the environment, are not being investigated to an extent commensurate with their significance. They have become 'orphans' within their discipline.

Orphans by definition lack parents, but in addition to familial isolation 'botanical' orphans share other characteristics found in human orphans: they often lack known close relatives, are misunderstood, excluded from 'family' events, unnamed, ignored or overlooked, have few carers, and are inadequately provided for. Data are presented to test the hypothesis that there are 'botanical' orphans relating to each of these criteria.

What is Botany?

The first step in this enquiry must be to define 'botany'. The word derives from one used in ancient Greece to mean grass, fodder or pasture. The first book title using the word in a classificatory sense appears to be the *Pinax Theatri Botanici* (Bauhin 1623) which included algae, mushrooms and lichens as well as vascular plants, bryophytes and ferns. The first usage in English recorded in the *Oxford English Dictionary* (1971) is by Ray in a letter dated 1696 (Dereham 1718), and the definition of botany in that *Dictionary* is 'the science which treats of plants'. *Collins Reference Dictionary of Biology* (1988) has 'the scientific study of the plant kingdom, usually including microorganisms'. Surprisingly, or perhaps intentionally, *The Penguin Dictionary of Botany* (Blackmore and Tootill 1984) fails to define 'botany', although its Preface indicates pure and applied plant sciences and the work includes algae, fungi and even some prokaryotes.

Evidence for a definition in practice is seen in the scope of botanical gardens and other institutions, botany departments, botanical meetings, societies, journals, and textbooks of botany. These are invariably found to include, to a greater or lesser extent, algae, bryophytes, ferns, and fungi (including lichens) in addition to flowering plants. The number of possible examples is overwhelming, but indicative are the contents of reference collections listed in *Index Herbariorum* (Holmgren *et al.* 1990), the subjects of papers in journals such as the *Canadian Journal of Botany*, symposium titles at International Botanical Congresses, and papers commemorating botanical anniversaries (e.g. Wagner 1974; Short 1990). That not all 'botanical' departments, institutions, meetings, journals and books hold or treat organisms other than vascular plants is an observation pertinent to the 'orphan' hypothesis.

Bacteria (and often also viruses) were regularly to be found in textbooks of botany into the 1960s (e.g. Brimble 1964). This tradition has even been maintained in at least one influential text (Raven *et al.* 1992), but in general bacteria and viruses are now almost exclusively confined to departments, societies, journals, textbooks and meetings labelled 'microbiology', a not entirely appropriate term (Cowan 1978). A complication is that microbiology as currently interpreted in practice encompasses some groups still also treated in 'botanical' fora, notably algae, cyanobacteria, and fungi (Hawksworth 1992). Interestingly, in universities with no microbiological departments or microbiologists, prokaryote teaching invariably reverts to departments of botany or other botanists on the faculty.

The *International Code of Botanical Nomenclature* (Greuter *et al.* 1994: Pre. 7) covers 'all organisms traditionally treated as plants ... e.g., blue-green algae (*Cyanobacteria*); fungi including chytrids, oomycetes and slime moulds; photosynthetic protists and taxonomically related non-photosynthetic groups' and not only those referred to the kingdom *Plantae*. 'Fungi' in the sense of the Code are defined as 'including slime moulds and lichen-forming fungi' (Art. 13.1d).

What are the 'Botanical' Orphans?

For the purposes of the subsequent analysis in this contribution, I posit that the algae, cyanobacteria, fungi (including lichens) and photosynthetic protists are all treated as putative 'botanical' orphans. In my discussions, I will emphasise the non-photosynthetic heterotrophic groups, as the photosynthetic ones were considered in depth separately by other contributors to the 'Beyond the Floras' Conference, with the exception of the ecological units termed 'lichens'.

The Characteristics of 'Botanical' Orphans

The evidence to test the hypothesis that the organism groups cited above merit the appellation 'orphans', can be presented by each of the characteristics encountered amongst orphaned humans.

(a) Lacking Close Relatives

It has been recognised for many generations that Life on Earth cannot be simply divided into two kingdoms, *Animalia* and *Plantae*. A five-kingdom system has been widely used since promulgated by Whittaker (1969), which also distinguished the *Fungi*, *Monera* and *Protista* at the same rank; all but *Animalia* included organisms historically studied by botanists. Molecular work has shown that systems based on ultra-structural differences, ciliation, cell-wall composition, chlorophylls, phycobilins and

lysine synthesis were not only robust but merit further higher categories — especially as an enormous molecular diversity amongst uncultured bacterial groups has become apparent. There is now general agreement that two domains or superkingdoms should be recognised, *Prokarya* and *Eukarya*. The former includes the *Archaea* and *Bacteria* (including *Cyanobacteria*) and the latter *Animalia*, *Chromista*, *Fungi*, *Plantae* and *Protozoa* (Cavalier-Smith 1993; Corliss 1994). A few authors still unite *Chromista* and *Protozoa* into the *Protoctista* (or *Protista*; e.g. Margulis 1996), but this can now be justified only by pragmatic rather than phylogenetic arguments.

As molecular data accumulate, evidence that more higher categories merit recognition is emerging. Sogin *et al.* (1996) suggest that at least two main categories in *Eukarya* should be recognised within what others have termed *Chromista*; they informally refer to these as 'alveolates' (including dinoflagellates) and 'stramenopiles' (including diatoms, oomycetes, labyrinthulids, brown algae, and chrysophytes).

The data now available suggests that the *Fungi* are more closely allied to the *Animalia* than to the *Plantae* (Wainright *et al.* 1993), and that some of the organisms formerly regarded as fungi belong not in the kingdom *Fungi*, but in the *Chromista* (or 'straminopiles'; i.e. the labyrinthulids and oomycetes) or *Protozoa* (i.e. the slime moulds). The term 'fungi' is consequently now best used in the colloquial sense of organisms traditionally studied by mycologists (Christensen 1990; Hawksworth 1991; Barr 1992; Hawksworth *et al.* 1995). A parallel argument exists for the use of the term 'algae' (Christensen 1990), which are now dispersed not only within different kingdoms of *Eukarya*, but also even extending into *Prokarya* for the cyanobacteria.

The cyanobacteria provide the most extreme case of distant relatives amongst the 'orphans'. These organisms were historically treated as blue-green algae, but molecular data accumulated from 1980 has established beyond doubt that they are true bacteria and belong in the kingdom *Bacteria* in the domain *Prokaryota* (Margulis 1996; Whitton 1992). The cyanobacteria are consequently now starting to receive increased attention from bacteriologists, although still studied by 'algologists', and their nomenclature remains subject to the *International Code of Botanical Nomenclature* (see above).

It is clear that orphan 'botanical' groups, other than bryophytes, do not have close relatives in *Plantae*.

(b) Misunderstood

Misunderstandings about some of the 'orphans' are of long-standing. For example, the genus *Mucor* as treated by Linnaeus (1753) also incorporated species of at least *Aspergillus*, *Calicium*, *Chaenotheca*, *Erysiphe* and *Penicillium*; Linnaeus also included four lichenised species in the 'algal' genus *Byssus*, and the cyanobacterial lichen *Leptogium lichenoides* lay hidden in the jelly-fungal genus *Tremella*.

It was not appreciated that lichens were composite structures formed of a fungus and(or) algae or cyanobacteria until 1867, and the nature and definition of lichens has been continuously and sometimes acrimoniously debated since that time (Hawksworth 1988; Hawksworth and Honegger 1994). Although since 1959 the *International Code of Botanical Nomenclature* has explicitly stated that names given to lichens refer to the fungal component, they were treated as if a separate class *Lichenes* until after the Thirteenth International Botanical Congress in Sydney in 1981. What was and was not considered a 'lichen' at least in part stemmed from what Acharius (1810) had treated in the *Lichenographia Universalis*; Fries held Acharius in the highest regard as the last pupil to defend his thesis in the presence of Linnaeus, and included in the *Systema Mycologicum* (Fries 1821–32) only fungi not considered to be lichens by Linnaeus. Indeed, there is evidence for occasional correspondence between them on this topic.

This has meant that some non-lichenised fungi continue to this day to be studied by lichenologists (e.g. *Chaenothecopsis*, *Leptorhaphis*, *Stenocybe*). In practice single genera can even include both lichenised and non-lichenised species, or have different biological strategies according to the stage in their life life-histories (e.g. *Caloplaca*, *Diploschistes*, *Mycomicrothelia*, *Rhizocarpon*, *Toninia*). The polyphyletic origin of lichens has been generally accepted by ascomycete systematists since the mid-1970s, and is now indisputably confirmed by molecular data (Gargas *et al.* 1995). Lichen-forming fungi are now being routinely included in overall classification systems, checklists, and mycological text-books (e.g. Hawksworth *et al.*, 1995; Alexopoulos *et al.*, 1996). As in the case of other ecological groups of fungi, such as entomopathogens, mycorrhizas, or plant pathogens, this does not preclude pragmatic accounts of fungi with biological strategies held in common.

Yet lichens continue to be misunderstood. A separate phylum name, *Mycophycophyta*, was used by Margulis (1993) including basidiomycete and ascomycete lichens with algae and cyanobacteria — a ‘phylum’ polyphyletic to the extent of including elements from three kingdoms. Lichens have even being included in the *Flora of Australia* from 1992, rather than the *Fungi of Australia* series started in 1996; an anachronistic situation that perhaps merits a revisit.

(c) Unnamed

There has been considerable debate generated on the issue of estimating the numbers of known and undescribed species on Earth. The various estimates proposed have been assessed in the UNEP *Global Biodiversity Assessment* (Heywood 1995) and working figures recommended (Table 1). Accepting that there are wide margins for potential error in these calculations, the differences in the percentages of the known vs estimated species for the different ‘botanical’ groups are, nevertheless, striking. Whereas 84.4% of the Earth’s plants have been described, the proportions for algae, bacteria and fungi are 10, 0.04 and 4.8% respectively. Ninety percent or more of the orphans remain unnamed.

The date by which the inventory for each group will be completed at current rates of species description (where available) are also staggeringly divergent. The year 2024 seems not unreasonable for vascular plants, but contrasts markedly with 2888 for fungi, and even more dramatically with 10295 for bacteria. This pattern is mirrored at the national level. For example, in the British Isles (where for this purpose the native plants can be considered 100% known) those changes that occur are largely from revisions in taxonomy, and the total has remained at around 2,100 for the last 40 years. In the case of the fungi, the British list has increased by 100% over this same period (Hawksworth 1991). It is still not too difficult to find fungi new to science in the British Isles, mycologically the world’s best-studied country; on average 46 species of fungi new to science are still described from the country every year (Hawksworth 1993).

Table 1. Known and estimated global species numbers (in thousands) for selected ‘botanical’ groups, with rates of species description and the estimated year of completion of the inventory (based on data in Heywood 1995)

Group	Known species	Estimated species	Percentage known	Described per year	Estimated year of completion
Algae	40	400	10.0	unknown	unknown
Bacteria	4	1,000	0.04	120	10295
Fungi	72	1,500	4.8	1,600	2888
Plants	270	320	84.4	1,700	2024

Against this background, the task of completing the inventory of Australian fungi is especially daunting as so little exploration has yet been carried out. In the five years 1991–95, 405 species of fungi (including lichen-forming species) were catalogued as newly described from Australia in the *Index of Fungi*. Pascoe (1990) argued that the number of fungi in Australia could be 10 times the number of Australian plants, i.e. 250,000. The actual number of fungi already known in the country is unlikely to be more than 5,000 (including lichen-forming groups), suggesting 245,000 may await discovery. If all were new for science, at the rate of description seen in the last five years it would take another 3,025 years to complete the task. In practice, many will have been described from other regions, but even assuming that 50% were new, the task would take until the year 3508 at current levels of resourcing. The *Fungi of Australia* will require careful long-range planning and megascience scale financing.

The extent of novelty in all 'orphan' groups challenges us to adopt new methods of working and to determine priority groups for systematic research (Hawksworth and Ritchie 1993; Rossman 1995; Cannon 1997; Hawksworth *et al.* 1997; Hyde and Hawksworth 1997).

(d) Excluded from Family Events

Orphans can be expected to be excluded from or marginalised at family events. Few botanists working on orphan groups belong to general botanical societies, especially where there are active national or international bodies catering for their specialities. For example, the Botanical Society of the British Isles (BSBI) specifically advertises itself as 'the major source of information on the status and distribution of British and Irish flowering plants and ferns'; since 1836 the Society and its forerunners only had vascular plant specialists as President's, although two also 'straying' into bryophytes were accepted (Allen 1986). The International Association for Plant Taxonomy (IAPT), is 'concerned with botany in the traditional broad sense [and] embraces all organisms within the mandate of the *International Code of Botanical Nomenclature*, regardless of their current disposition in particular kingdoms'; it had 91 mycologists (including lichenologists) as personal members in 1994, 10.3% of the 808 membership.

This same pattern of no or minimal representation at 'botanical' parties, is seen in congresses, workshops and symposia. The most recent International Botanical Congress (IBC) is illustrative. The Fifteenth IBC, held in Yokohama, Japan in 1993, included 211 symposia; only 8 (3.8%) concerned algae and 11 (5.2%) fungi. The 'orphans' now largely have their own international congresses, for example the International Mycological Congress series initiated in 1971.

(e) Ignored or Overlooked

Many 'botanical' and 'plant' texts ignore the 'orphans'. While this can be justified where 'plant' is used in the sense of *Plantae*, this is hardly defensible for 'botany' in its traditional interpretation. In works that do mention them at all, the treatments tend to be disproportionate to the extent of diversity in the 'orphan' groups. An analysis of the contents of five tertiary-level texts which have appeared over the last four decades revealed that while not less than 38% of the pages were devoted to vascular plants, no 'orphan' group attained more than 8% (Table 2).

The coverage in five 'botanical' journals for the 10 years 1985–95 was analysed and found to be in a similar mould (Table 3). Not more than 15% of the total pages were devoted to any 'orphan' group in any of these journals, compared with 77–90% allocated to vascular plants. The complete runs of two Australian 'botanical' journals, the *Australian Journal of Botany* and *Muelleria*, were then assessed to determine if the pattern had changed over the last 40 years (Table 4); it had not.

Table 2. Space allocations (% pages) botany textbooks

Textbooks	General	Bacteria & Viruses	Algae	Fungi	Bryophytes	Vascular Plants
McLean and Ivimey-Cook (1951-73)	16.5	0.5	4	4.5	0.5	74
Brimble <i>et al.</i> (1960)	39	0.5	4	7	2	48
Weier <i>et al.</i> (1982)	39	5	6.5	8	3.5	38
Sitler <i>et al.</i> (1991)	34.5	1.5	6	6	2.5	50
Raven <i>et al.</i> (1992)	32.5	4.5	6	6	2.5	48

Table 3. Space allocations (% pages) in botanical journals 1985-1995

Journal	Bacteria & Viruses	Algae	Fungi	Bryophytes	Vascular Plants
<i>Australian Journal of Botany</i>	0.5	2	11	0.5	86
<i>Muelleria</i>	—	3	15	—	82
<i>Nordic Journal of Botany</i>	0.1	12.5	10	—	77.4
<i>Plant Systematics and Evolution</i>	0.05	4.6	4.6	0.15	90.6
<i>Taxon</i>	—	4.0	4.5	6.5	85

Table 4. Space allocations (% pages) in two Australian botanical journals

Volume (Year)	Bacteria & Viruses	Algae	Fungi	Bryophytes	Vascular Plants
<i>Australian Journal of Botany</i>					
1-5 (1953-57)	—	3.	3.5	1	92.5
6-10 (1958-62)	—	6.5	1.5	2	90
11-15 (1963-67)	—	10	13.5	—	76.5
16-20 (1968-72)	0.5	12	11	—	76.5
21-25 (1973-77)	1.5	18	14	2	64.5
26-30 (1978-82)	0.5	6	14.5	—	79
31-35 (1983-87)	0.5	3.5	14	0.5	81.5
36-40 (1988-92)	0.25	—	10	0.25	89.5
41-43 (1993-95)	—	—	8.5	—	91.5
Mean	0.5	6.5	10	0.5	82.5
<i>Muelleria</i>					
1 (1955-67)	—	9	22	4	65
2 (1969-73)	—	1	4	11	84
3 (1974-77)	—	—	26	5	69
4 (1978-81)	—	1.25	8	1.25	89.5
5 (1982-84)	—	—	4	—	96
6 (1985-88)	—	—	13.5	—	86.5
7 (1989-92)	—	4	13.5	—	82.5
8 (1993-95)	—	5	18.5	—	76.5
Mean	—	2.5	13.5	3	81

(f) With Few Carers

The issue of the shortage of systematists world-wide has been widely publicised; the total number of scientists describing new organisms world-wide stands at around 7,000 (Heywood 1995). The issue entered the intergovernmental arena at the second meeting of the Subsidiary Body on Scientific, Technological and Technical Advice (SBSTTA) to the Convention on Biological Diversity in Montreal in September 1996; the recommendations from that meeting were subsequently endorsed at the Third Conference of the Parties to the Convention in Buenos Aires in November 1996. Nations are realising that systematic services are necessary to enable them to meet their obligations under the Convention.

The situation is particularly acute in the species-rich groups, especially the putative 'orphans'. In the case of Australia, Pascoe (1990) noted that only 26 taxonomic mycologists were present in the country, 11 of whom were lichenologists. As a result of a questionnaire, Grgurinovic and Hyde (1993) reported that there were 32 researchers in Australia spending some time on taxonomic mycology; half devoted less than 20 h each month on research, and five were concerned with only three economically important genera. These authors list 55 orders of fungi on which there have been no publications by Australian authors in the years 1988–91. This issue is returned to in the contribution by Hyde (1997).

The level of 'carers', both researchers and curators, can also be reflected in institutional structures. Zoologists learnt long ago that the recognition of more departments was a key to gaining more curators and researchers. In many cases, botany is a single department whereas zoology is distributed through several. For example, in the Royal Ontario Museum in Toronto, zoology is represented by seven departments and has 67 staff; botany is a single department with seven staff, yet encompasses organisms from five and not part of one kingdom (Royal Ontario Museum 1993; Table 5). In such structures, 'orphans' are proportionately disadvantaged; within botany at the ROM, mycology is represented by one research fellow and half of a technician.

(g) Inadequately Provided for

The numbers of botanical institutions which hold reference material of the 'orphan' groups are considerable world-wide, but the collections are generally small, restricted in scope, and lack specialist staff. Data collected by Walker (1980) indicated that in Australia there were then about 244,000 fungal (including lichen) specimens and cultures distributed through 62 institutions, eight of those institutions accounting for 150,000 of the collections. The figure of 244,000 constitutes 4.6% of the 5.3 million

Table 5. Structure of the biological departments and numbers of personnel in the Royal Ontario Museum, Toronto in 1993 (Royal Ontario Museum 1993)

Department	Personnel
Botany	7
Entomology	6
Ichthyology and Herpetology	11
Invertebrate Palaeontology	10
Invertebrate Zoology	7
Mammology	12
Ornithology	12
Vertebrate Palaeontology	9

botanical specimens housed in 38 Australian collections (Holmgren *et al.* 1990; Heywood 1995). The situation for algae is similar, 204,000 collections, 3.8% of the total, being contained in seven collections (Richardson and McKenzie 1992).

The situation is similar in the case of other genetic resource collections in Australia. There are 101,000 vascular plants in Australia's botanical gardens and 94,000 accessions in seed banks, yet a mere 2,202 fungi are maintained in culture in the country (Heywood 1995).

Inadequate in-country capacity has implications for where specialists will deposit critical material. Of the 405 species of fungi described as new from Australia in the period 1991–95, the name-bearing types of 136 (33%) were deposited in reference collections outside the country. While this percentage is not exceptional and conforms to the general pattern (Hawksworth and Kirk 1995), the absence of key reference material in the country will constrain the speed with which Australian mycologists can progress their systematic work.

Some Australian botanists have questioned the value of reference collections (Clifford *et al.* 1990). Acquisitions and curatorial policies certainly need to be kept under review, but reference collections of all kinds are a major facility required for diverse purposes. Grgurinovic and Walker (1993) stress the crucial role of fungal collections in identification, determination of host and geographic ranges, quarantine, and biocontrol. With so few mycological systematists, and with so many fungi being either unnamed or belonging to groups yet to be critically revised, collections are the key reference point for validating published reports of all kinds. Collections also have largely untapped potential; preserved material of lichenised and other fungi can aid bioprospecting for secondary metabolites (Paterson and Hawksworth 1985; Elix 1992). DNA can also be extracted and amplified from both dried cultures and specimens for use in systematic and other investigations (Wingfield and Wingfield 1993). I have recently addressed the importance of microbial genetic resource collections to biodiversity and biosystematics elsewhere (Hawksworth 1996).

The decision to close the Biological and Chemical Research Institute (BCRI) at Rydalmer and relocate the fungal collections to new facilities in Orange was confirmed in August 1996. This action has concerned mycologists world-wide as the Rydalmer collection is the most important for mycology in the continent. Careful planning and adequate resourcing will be needed if the effectiveness of the collection is to be not only maintained but enhanced. An independent review of the effects of the break-up of BCRI is recommended after 3–5 years (Standing Committee on State Development 1996); if that is not positive it will record a major set-back to Australian mycology.

Why 'Botanical' Orphans Should be Valued

There are multifarious reasons why 'botanical' orphans should be valued, and three are introduced here as indicative.

(a) Ecological Processes

The various 'orphan' groups are responsible for a variety of crucial roles in ecosystem functioning and plant health. Their significance is becoming increasingly apparent as ecological processes are examined in depth. Organisms forming mutualistic associations with plants are of especial significance, notably mycorrhizal and endophytic fungi. Mycorrhizas can bind together communities and translocate nutrients that limit plant growth (Read 1996), influencing the quality and quantity of below-ground carbon (Rygielwicz and Andersen 1994), and endophytes produce metabolites inhibiting insect pests (Clay 1990).

Photosynthetic 'orphan' groups fix substantial amounts of carbon dioxide at the global scale. They constitute up to 80% of the primary productivity and biomass in open oceans (Andersen 1992).

Others, mainly fungi, are crucial to the cycling of nutrients from dead and waste biotic materials of all kinds; fungi are essential to lignin breakdown. It is also becoming apparent that lichens and other rock microbiota have a significant role in rock weathering and contribute to global carbon sequestration (Schwartzman 1993), and that lichens cannot be ignored in studies of nitrogen fixation and nutrient fluxes in forests. In one oak wood in California, the lichen litter was almost twice as rich in nitrogen as fallen leaves, and contributed substantially more nitrogen deposition than would be inferred from the mass of the litter alone (Nash 1996). Fungi are also emerging as a key source of food for insects in the tropics; one study in Sulawesi, based on 1.1 million beetle specimens, revealed that 23.4% of the species were fungivores (Hammond 1990).

The extent of soil surface stabilisation by both free-living cyanobacteria and lichens is also not always appreciated. The communities often involve rather few species, are fragile, and are particularly vulnerable to trampling or driving. Once lost, the surfaces are exposed and subject to heightened erosion, but fast-growing microscopic algae and cyanobacteria also have potential for halting or reversing desert encroachment (Painter 1993). Soil surface stabilisation is a significant role for the 'orphans' in desert regions throughout the world (Kappen 1988), and is a topic meriting particular attention in Australia (Rogers 1982).

For supplemental information see Andersen (1992), Dix and Webster (1995), Heywood (1995), Rayner (1995), and Lodge *et al.* (1996).

(b) Bioindicators of Ecosystem Health

Many of the 'orphans' live in intimate associations with their environment and are therefore particularly vulnerable to changes in ecological conditions. This is especially so for lichens which, because of their longevity, are well-established and widely used as bioindicators of certain gaseous air pollutants, and as bioaccumulators for heavy metals and radionuclides (Gilbert 1992; Richardson 1992; Huckaby 1993). There is also a correlation between the frequency of mycorrhizal fungi and tree health under the influence of acid rain, and these fungi can serve as early bioindicators of impending forest damage before symptoms are visible in the trees (Arnolds 1991).

The 'orphans' can also serve as bioindicators of other types of environmental perturbations. Certain lichens have restricted powers of dispersal and require a continuity of trees to persist, and the proportion of these present in a site is indicative of the extent to which ecological continuity has been maintained (Rose 1992). In the tropics leaf-surface mosaics of algae, superficial microfungi, hepatics, and lichens have similar values. Lücking (1995) has elegantly demonstrated the relationship between forest disturbance and foliicolous lichens in Costa Rica.

The application of lichens on rocks at the sides and in rivers and lakes as indicators of water levels also merits attention. The pioneering work of Gregory (1976) near Armidale in New South Wales is noteworthy in this respect.

(c) Source of Exploitable Attributes

The commercial value of pharmaceuticals obtained from fungi is widely appreciated, and bioprospecting has been an element in the drug discovery programmes of major pharmaceutical companies for the last 50–60 years (Nisbet and Fox 1991). Wonder-drugs are few and far between, but surprises can come from unexpected sources; global sales of cyclosporin, the drug from *Tolypocladium inflatum* routinely used to reduce organ rejection in human organ transplant surgery, reached US \$ 1.29 billion in 1995 —

substantially exceeding that even of paracetamol. Taxol, the anti-tumor drug obtained from the bark of the Pacific yew in the USA, has also now been found to be produced by a new endophytic fungus *Taxomyces andreanae* (Stierle *et al.* 1993).

Conclusion

The data presented here support the hypothesis that algae and fungi meet the criteria which justify their designation as orphans in 'botanical' diversity. No data to negate this contention were found. It is also evident that 'botanical' orphans merit human attention from both altruistic and selfish motives: altruism from other biologists because of their actual and potential importance to the environment and human well-being, and selfishness from their underresourced practitioners.

Orphans must be wary of too much special pleading. The flagrant beggar pulling at the sleeves of a more affluent passer-by may be less successful than one in obvious need crouched in doorway. Mycologists have been pressing their case for decades. The pamphlet *The Need for Encouraging the Study of Systematic Mycology in England and Wales*, prepared by a committee of the British Mycological Society, was distributed to Government departments in 1944 (British Mycological Society 1949); it had no marked impact. Any demands must be perceived as reasonable, and I submit that it is not unreasonable to request a level of support commensurate with their importance and that received by the 'nuclear family'.

In order to progress, a heightened awareness of the importance of the orphans is essential. I have previously argued that each mycologist needs to be involved in asserting the identity of their subject, have a shared and personal mission, and create a segment of his or her time to act for this cause (Hawksworth 1995). If each scientist working with an orphan group also became an active chauvinist, the lobby could not continue to be unheeded. The climate is already starting to change, as evidenced by the coverage of orphans in UNEP's *Global Biodiversity Assessment* (Heywood 1995), and the vision of launching the *Fungi of Australia*. These signals should not occasion complacency, but encourage us to build further so that the level of our knowledge of the different orphan groups will be more appropriate to their numbers and relevance by the time of the bicentennial of the Royal Botanic Gardens in Melbourne.

Acknowledgments

I am indebted to the Royal Botanic Gardens, Melbourne for the opportunity to participate in the celebration of its sesquicentenary, and to Dr B. Aguirre-Hudson for assistance in compiling the analyses of publications included in this paper.

References

- Acharius, E. (1810). 'Lichenographia Universalis.' (I.F. Danckwerts: Gottingen.)
- Alexopoulos, C.J., Blackwell, M., and Mims, C.W. (1996). 'Introductory Mycology.' 3rd edn. (John Wiley & Sons: New York.)
- Allen, D.E. (1986). 'The Botanists.' (St Paul's Bibliographies: London.)
- Andersen, R.A. (1992). Diversity of eukaryotic algae. *Biodiversity and Conservation* **1**, 267–92.
- Arnolds, E. (1991). Mycologists and nature conservation. In 'Frontiers in Mycology'. (Ed. D.L. Hawksworth.) pp. 243–64. (CAB International: Wallingford.)
- Barr, D.J. (1992). Evolution and kingdoms or organisms from the perspective of a mycologist. *Mycologia* **84**, 1–11.
- Bauhin, C. (1623). 'Pinax Theatri Botanici.' (King Ludovic: Basel.)

- Blackmore, S., and Tootill, E. (1984). 'The Penguin Dictionary of Botany.' (Penguin Books: London.)
- Brimble, L.J. F., Williams, S., and Bond, G. (1960) 'Intermediate Botany'. 4th edn. (Macmillan: London.)
- British Mycological Society (1949). The need for encouraging the study of systematic mycology in England and Wales. *Transactions of the British Mycological Society* **32**, 104–12.
- Cannon, P.F. (1997). Strategies for rapid assessment of fungal diversity. *Biodiversity and Conservation* (in press).
- Cavalier-Smith, T. (1993). Kingdom *Protozoa* and its 18 phyla. *Microbiological Reviews* **57**, 953–94.
- Christensen, T. (1990). Plants, animals, algae and fungi, four non-taxonomic group designations. *Taxon* **39**, 93–4.
- Clay, K. (1990). Fungal endophytes of grasses. *Annual Review of Ecology and Systematics* **21**, 275–97.
- Clifford, H.T., Rogers, R.W., and Dettmann, M.E. (1990). Where now for taxonomy? *Nature* **346**, 602.
- Collins Reference Dictionary of Biology (1988). 'Collins Reference Dictionary of Biology.' (Collins: London.)
- Corliss, J.O. (1994). An interim utilitarian ('user-friendly') hierarchical classification and characterization of the protists. *Acta Protozoologica* **33**, 1–51.
- Cowan, S.T. (1978). 'A Dictionary of Microbial Taxonomy.' (Cambridge University Press: Cambridge.)
- Dereham, W. (1718). 'Philosophical Letters between Mr Ray and several of his Correspondents, to which are added those of Francis Willughby.' (London.)
- Dix, N.J., and Webster, J. (1995). 'Fungal Ecology.' (Chapman and Hall: London.)
- Elix, J.A. (1992). Lichen chemistry. *Flora of Australia* **54**, 23–9.
- Fries, E.M. (1821–32). 'Systema Mycologicum.' 3 vols. (1 & 2, Berling: Lund; 3, E. Mauritz: Greifswald.)
- Gargas, A., DePriest, P.T., Grube, M., and Tehler, A. (1995). Multiple origins of lichen symbiosis in fungi suggested by SSU rDNA phylogeny. *Science* **268**, 1492–5.
- Gilbert, O.L. (1992). Lichen reinvasion with declining air pollution. In 'Bryophytes and Lichens in a Changing Environment'. (Eds J.W. Bates and A.M. Farmer.) pp. 159–77. (Oxford Science Publications: Oxford.)
- Gregory, K.J. (1976). Lichens and the determination of river channel capacity. *Earth Surface Processes* **1**, 273–85.
- Greuter, W., Barrie, F., Burdet, H.M., Chaloner, W.G., Demoulin, V., Hawksworth, D.L., Jørgensen, P.M., Nicolson, D.H., Silva, P.C., Trehane, P., and McNeill, J., Eds (1994). 'International Code of Botanical Nomenclature (Tokyo Code).' (Regnum Vegetabile No. 131.) (Koeltz Scientific Books: Königstein.)
- Grgurinovic, C., and Hyde, K.D. (1993). The status of taxonomic mycology in Australia in 1991. *Australian Plant Pathology* **22**, 42–7.
- Grgurinovic, C., and Walker, J. (1993). Herbaria and their place in science: a mycological and plant pathological perspective. *Australian Plant Pathology* **22**, 14–8.
- Hammond, P.M. (1990). Insect abundance and diversity in the Dumoga-Bona National Park, N. Sulawesi, with special reference to the beetle fauna of lowland rain forest in the Toraut region. In 'Insects and the Rain Forests of South East Asia (Wallacea)'. (Eds W.J. Knight and J.D. Holloway.) pp. 197–254. (Royal Entomological Society of London: London.)
- Hawksworth, D.L. (1988) The variety of fungal-algal symbioses, their evolutionary significance, and the nature of lichens. *Botanical Journal of the Linnean Society* **96**, 3–20.
- Hawksworth, D.L. (1991). The fungal dimension of biodiversity: magnitude, significance, and conservation. *Mycological Research* **95**, 641–55.
- Hawksworth, D.L. (1992). Biodiversity in microorganisms and its role in ecosystem function. In 'Biodiversity and Global Change'. (Eds O.T. Solbrig, H.M. van Emden and P.G.W.J. van Oordt.) pp. 83–93. (IUBS: Paris.)
- Hawksworth, D.L. (1993). The tropical fungal biota: census, pertinence, prophylaxis, and prognosis. In 'Aspects of Tropical Mycology'. (Eds. S. Isaac, J.C. Frankland, R. Watling and A.J.S. Whalley.) pp. 265–93. (Cambridge University Press: Cambridge.)
- Hawksworth, D.L. (1995). Challenges in mycology. *Mycological Research* **99**, 127–8.
- Hawksworth, D.L. (1996). Microbial collections as a tool in biodiversity and biosystematic research. In 'Culture Collections to Improve the Quality of Life'. (Eds R.A. Samson, J.A. Stalpers, D. van der Mei and A.H. Stouthamer.) pp. 26–35. (Centraalbureau voor Schimmelcultures: Baarn.)

- Hawksworth, D.L., and Honegger, R. (1994) The lichen thallus: a symbiotic phenotype of nutritionally specialized fungi and its response to gall producers. In 'Plant Galls'. (Ed. M.A. Williams.) pp. 77–98. (Systematic Association Special Vol. 49; Clarendon Press: Oxford.)
- Hawksworth, D.L., and Kirk, P.M. (1995). Passing round the standards. *Nature* **378**, 341.
- Hawksworth, D.L., Kirk, P.M., Sutton, B.C., and Pegler, D.N. (1995). 'Ainsworth & Bisby's Dictionary of the Fungi.' 8th edn. (CAB International: Wallingford.)
- Hawksworth, D.L., Minter, D.W., Kinsey, G.F. and Cannon, P.F. (1977). Inventorying a tropical fungal biota: intensive and extensive approaches. In 'Tropical Mycology'. (Eds K.K. Janandhanan, C. Rajendran, K. Natarajan and D.L. Hawksworth.) in press (Oxford and IBH Publishing: New Delhi.)
- Hawksworth, D.L., and Ritchie, J.M. (1993). 'Biodiversity and Biosystematic Priorities: Microorganisms and invertebrates.' (CAB International: Wallingford.)
- Heywood, V.H., Ed. (1995). 'Global Biodiversity Assessment.' (Cambridge University Press: Cambridge.)
- Holmgren, P.K., Holmgren, N.H., and Barnett, L.C. (1990). 'Index Herbariorum. Part I. The Herbaria of the World.' 8th edn. (New York Botanical Garden: New York.)
- Huckaby, L.S. (Ed.) (1993). Lichens as bioindicators of air quality. USDA Forest Service General technical Report RM-224, Fort Collins.
- Hyde, K.D. (1997). Who will take care of the orphans? *Muelleria*, **10**, 139–44.
- Hyde, K.D., and Hawksworth, D.L. (1997). Measuring and monitoring the biodiversity of microfungi. In 'Tropical Fungal Diversity'. (Ed. K.D. Hyde.) in press. (University of Hong Kong Press: Hong Kong.)
- Kappen, L. (1988). Ecophysiological relationships in different climatic regions. In 'Handbook of Lichenology'. Vol. 2. (Ed. M. Galun.) pp. 37–100. (CRC Press: Boca Raton, Florida.)
- Linnaeus, C. (1753). 'Species Plantarum.' 2 vols. (Laurentius Salvius: Stockholm.)
- Lodge, D.J., Hawksworth, D.L., and Ritchie, B.J. (1996). Microbial diversity and tropical forest functioning. In 'Biodiversity and Ecosystem Processes in Tropical Forests'. (Eds G.H. Orians, R. Dirzo and J. H. Cushman.) pp. 69–100. (Springer-Verlag: New York.)
- Lücking, R. (1995). Biodiversity and conservation of foliicolous lichens in Costa Rica. *Mitteilungen der Eidgenössischen Forschungsanstalt für Wald, Schnee und Landschaft* **70**, 63–88.
- Margulis, L. (1993). 'Symbiosis and Cell Evolution: Microbial communities in the Archean and Proterozoic eons.' 2nd edn. (Freeman: New York.)
- Margulis, L. (1996). Archaeal-eubacterial mergers in the origin of *Eukarya*: phylogenetic classification of life. *Proceedings of the National Academy of Sciences, USA* **93**, 1071–6.
- McLean, R.C., and Ivimey-Cook, W.R. (1951–73). 'Textbook of Theoretical Botany.' 4 vols. (Longman Green: London.)
- Nash, T.H. (1996). Nutrients, elemental accumulation and mineral cycling. In 'Lichen Biology'. (Ed. T.H. Nash.) pp. 136–53. (Cambridge University Press: Cambridge.)
- Nisbet, L.J., and Fox, F.M. (1991). The importance of microbial biodiversity in biotechnology. In 'The Biodiversity of Microorganisms and Invertebrates: its Role in Sustainable Agriculture'. (Ed. D.L. Hawksworth.) pp. 229–44. (CAB International: Wallingford.)
- Oxford University Press (1971). 'The Compact Edition of the Oxford English Dictionary.' 9th edn. (Oxford University Press: New York.)
- Painter, T.J. (1993). Carbohydrate polymers in desert reclamation: the potential of microalgal bio-fertilizers. *Carbohydrate Polymers* **20**, 77–86.
- Pascoe, I.G. (1990). History of systematic mycology in Australia. In 'History of Systematic Botany in Australasia'. (Ed. P.S. Short.) pp. 259–64. (Australian Systematic Botany Society: South Yarra.)
- Paterson, R.R.M., and Hawksworth, D.L. (1985). Detection of secondary metabolites in dried cultures of *Penicillium* preserved in herbaria. *Transactions of the British Mycological Society* **85**, 95–100.
- Raven, P.H., Evert, R.F., and Eichhorn, S.E. (1992). 'Biology of Plants.' 5th edn. (Worth Publishers: New York.)
- Rayner, A.D.M. (1995). Fungi, a vital component of ecosystem functioning in woodland. In 'Microbial Diversity and Ecosystem Function'. (Eds D. Allsopp, R.R. Colwell and D.L. Hawksworth.) pp. 231–251. (CAB International: Wallingford.)
- Read, D.J. (1996). The nature and extent of mutualism in the mycorrhizal symbioses. In 'A Century of Mycology'. (Ed. B.[C.] Sutton.) pp. 255–91. (Cambridge University Press: Cambridge.)

- Richardson, B.J., and McKenzie, A.M. (1992). Australia's biological collections and those who use them. *Australian Biologist* **5**, 19–30.
- Richardson, D.H.S. (1992). 'Pollution Monitoring with Lichens.' (Richmond Publishing: Slough.)
- Rogers, R.W. (1982). Lichens of arid Australia. *Journal of the Hattori Botanical Laboratory* **53**, 351–5.
- Rose, F. (1992). Temperate forest management: its effects on bryophyte and lichen floras and habitats. In 'Bryophytes and Lichens in a Changing Environment'. (Eds J.W. Bates and A.M. Farmer.) pp. 211–33. (Oxford Science Publications: Oxford.)
- Rossman, A.Y. (1995). A strategy for an all-taxa inventory of fungal biodiversity. In 'Biodiversity and Terrestrial Ecosystems'. (Eds. C. Peng and C.H. Chou.) pp. 169–94. (Academia Sinica Monograph Series No. 14.; Institute of Botany, Academia Sinica: Taipei.)
- Royal Ontario Museum (1993). 'Royal Ontario Museum Forty-Third Annual Report, July 1992–June 1993.' (Royal Ontario Museum: Toronto.)
- Rygiewicz, P.T., and Andersen, C.P. (1994). Mycorrhizae alter quality and quantity of carbon below ground. *Nature* **369**, 58–60.
- Short, P.S. (Ed.) (1990). 'History of Systematic Botany in Australasia.' (Australian Systematic Botany Society: South Yarra.)
- Site, P., Ziegeler, H., Ehrendorfer, F., and Bresinsky, A. (Eds) (1991). 'Strasburger Lehrbuch der Botanik für Hochschulen: Begründet von E. Strasburger, F. Noll, H. Schenck, A.F.W. Schimper.' 33rd edn. (Gustav Fischer Verlag: Stuttgart.)
- Sogin, M.L., Morrison, H.G., Hinkle, G., and Silberman, J.D. (1996). Ancestral relationships of the major eukaryotic linkages. *Microbiologia SEM* **12**, 17–28.
- Standing Committee on State Development (1996). 'Report on rationales for closing the Veterinary Laboratories at Armidale and Wagga Wagga and the Rydalmer Biological and Chemical Research Institute.' (Parliament of New South Wales Legislative Council Report No. 12: Sydney).
- Schwartzman, D. (1993). Comment on 'Weathering, plants, and the long-term carbon cycle' by Robert A. Berner. *Geochimica et Cosmochimica Acta* **57**, 2145–6.
- Stierle, A., Strobel, G., and Stierle, D. (1993). Taxol and taxane production by *Taxomyces andreanae*, an endophytic fungus of Pacific yew. *Science* **260**, 214–6.
- Wagner, W.H., Ed. (1974). 25 years of botany. *Annals of the Missouri Botanical Garden* **61**, 1–261.
- Wainright, P.O., Hinkle, G., Sogin, M.L., and Stickel, S.K. (1993). Monophyletic origins of the Metazoa: an evolutionary link with fungi. *Science* **260**, 340–2.
- Walker, J. (1980). 'Mycological Herbaria and Culture Collections in Australasia.' (Department of Agriculture New South Wales: Rydalmer.)
- Weier, T.E., Stocking, C.R., Barbour, M.G., and Rost, T.L. (1982). 'Botany: An Introduction to Plant Biology.' 6th edn. (John Wiley & Sons: New York.)
- Whittaker, R.H. (1969). New concepts of kingdoms of organisms. *Science* **163**, 150–60.
- Whitton, B.A. (1992). Diversity, ecology, and taxonomy of the cyanobacteria. In 'Photosynthetic Prokaryotes'. (Eds N.H. Mann and N.G. Carr.) pp. 1–51. (Plenum Press: New York.)
- Wingfield, B.D., and Wingfield, M.J. (1993). The value of dried fungal cultures for taxonomic comparisons using PCR and RFLP analysis. *Mycotaxon* **46**, 429–36.